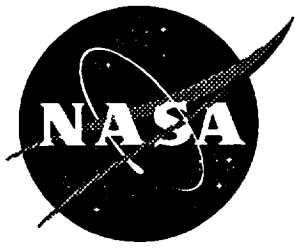

Pin Bearing Evaluation of LTM25 Composite Materials

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Contract NAS1-19347

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1.0 Introduction

This report summarizes the work performed on the contract NAS1-19347, Task 18. The contract NAS1-19347 Task 18 is an add on to the contract NAS1-19347, Task 14. Under the Task 18 contract, Northrop Grumman Corporation was contracted by NASA Langley to conduct pin bearing testing and fabricate two panels from composite materials that cure at low temperatures. These materials are being incorporated into Unmanned Aerial Vehicles (UAVs) to reduce manufacturing costs since it allows the use of low-cost tooling and facilities. Two composite prepreg product forms were evaluated; MR50/LTM25 unidirectional tape, batch 2881vd and CFS003/LTM25 woven cloth, batch 2216.

Northrop Grumman fabricated, machined, and tested specimens to determine the bearing strength in accordance with MIL-HDBK-17D, Volume 1, Section 7.2.4. Quasi-isotropic laminates from the two product forms were fabricated for these tests.

Additional 2 quasi-isotropic panels of 12 inches by 28 inches were fabricated (one each from the two product forms), inspected, and shipped to NASA for further evaluation. The laminate panels sent to NASA are detailed in Table 1.

Method of manufacture and inspection were similar to that used for the contract NAS1-19347, Task 14 and they are documented in detail in the final report titled "Property Evaluation of LTM25 Composites". The C-scan inspection results are summarized in Table 2 which also includes C-scan results for the panels shipped to NASA.

2.0 Panel and Specimen Machining

One quasi-isotropic panel was fabricated form each product forms for double shear pin bearing evaluation in accordance with MIL-HBBK-17D, Volume 1, Section 7.2.4. These panels did not include tabs. The specimens were machined to Figure 1.

3.0 Environmental Conditioning

All specimens backdried in a vacuum oven for 5 days at 160°F. The specimens were weighed before and after the backdry procedure. After backdrying, the -125°F and room temperature specimens were stored at 0°F in moisture proof bags until testing was performed.

The 180°F/wet specimens were moisture conditioned in a humidity chamber set at 160°F/98% R.H. Specimen moisture content was monitored by weighing the specimens. While in moisture conditioning, the specimens and traveler specimens were weighed frequently. The specimens were moisture conditioned until the moisture content target of 1% or higher was reached. After moisture conditioning, the 180°F/wet test specimens were stored at 0°F in moisture proof bags until testing was performed.

4.0 Double Shear Pin Bearing Test Procedure

4.1 Test Procedure

The procedure used follows the recommendations of MIL-STD-1312-B/Test Methods, "Fasteners Test Methods, X. Mechanically Attached Composite Shear Joint". The test specimens were not strain gaged. Each specimen was placed in the lower hydraulic grips of

the test frame. The loading block with bushings were hydraulically gripped in the upper region. Then the loading block was lowered and the its holes were aligned to that of the specimen and ST3M453-4-26 bolt was inserted and finger tightened with a nut. The temperature on the surface of the -125°F and 180°F specimens was held for 10 minutes prior to testing. All specimens were loaded in tension at a rate of 0.05 inch/minute until failure. The load versus deflection were recorded. The test matrix for pin bearing tests is shown in Table 3. The test setup for double shear pin bearing is shown in Figure 2.

4.2 Property Normalization

Normalization was conducted with respect to the measured ply thickness of each product form. The per ply thickness was determined by averaging all the specimen thicknesses tested in NAS1-19347 Task 14 for each product form. The per ply thicknesses were calculated to be 0.00576 inch and 0.00904 inch for MR50/LTM25 and CFS003/LTM25, respectively. These values were used to normalize some of the mechanical properties as follows:

Normalized value = (Actual value) x (specimen thickness / nominal thickness)

5.0 Test Results

5.1 Pin Bearing Tests

A detailed test results of the pin bearing properties are shown in Tables 4, 5 and Figures 3 through 6. These tables show the results for individual tests, failure mode, any test anomalies, and physical properties of the associated laminate from which the specimens were machined. Generally, the results for both product forms are very consistent except that the proportional limit load is higher that yield load at RTD for laminates made from CFS003/LTM25 woven product form. The different failure modes observed in the pin bearing tests are depicted in Figure 7. The load Displacement response of selected test specimens are shown in Figure 8 through 13.

5.2 Physical Results

The results for the physical testing are shown in Table 35. The tape laminate fall within the acceptable required values for resin content and fiber volume (RC 29% and FV 63%). The resin content of the woven panel, however, was typically higher than the required value of 41%. Similarly, the fiber content of the woven panels was slightly lower than the required value of 50%. Manufacturing proceeses for these material forms were similar to ones practiced in NAS1-19347 Task 14 and nothing unusual was observed during manufacturing to reflect on above discussion.

TABLE 1. DESCRIPTION OF PANELS SHIPPED TO NASA.

PANEL NUMBER	MATERIAL	DIMENSIONS (inches)	LAYUP*	NUMBER OF PLIES	DEBULK PROCEDURE
21	MR50/LTM25 TAPE	12 x 28	$[45/0/-45/90]_{2s}$	16	EVERY FOUR PLIES FOR 15 min.
22	CFS003/LTM25 WOVEN	12 x 28	$[45/0/-45/90]_{2s}$	16	EVERY FOUR PLIES FOR 15 min.

* THE 0° DIRECTION IS PARALLEL TO THE LONG EDGE OF THE PANELS

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TABLE 2. SUMMARY OF ULTRASONIC INSPECTION RESULTS.

PANEL NUMBER	ASDL NUMBER	MATERIAL	DIMENSIONS (inches)	AVERAGE dB LOSS
19	10379	TAPE[1]	17 x 33	12.65
20	10380	WOVEN[2]	17 x 33	9.10
21	10381	TAPE[1]	12 x 28	6.70
22	10382	WOVEN[2]	12 x 28	7.90

NOTES; 1. MR50/LTM25 UNIDIRECTIONAL TAPE, BATCH 2881 vd
2. CFS003/LTM25 WOVEN CLOTH, BATCH 2216

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TABLE 3. PIN BEARING TEST MATRIX FOR LTM25.

PRODUCT FORM	TEST METHOD	TEST REQUIREMENT	TEST CONDITION AND NUMBER OF SPECIMENS		
			-125°F/ DRY	RTD	180°F/ WET
TAPE	MIL-HDBK-17D VOL. 1, SEC. 7.2.4	PROPORTIONAL LIMIT, YIELD AND ULTIMATE LOADS	6	6	6
WOVEN	MIL-HDBK-17D VOL. 1, SEC. 7.2.4	PROPORTIONAL LIMIT, YIELD AND ULTIMATE LOADS	6	6	6

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Table 4. Pin Bearing Strength Test Results for MR50/LTM25 Unidirectional Tape.

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SPECIMEN ID	TEST ENVIRONMENT	SPECIMEN WIDTH (inch)	SPECIMEN THICKNESS (inch)	SPECIMEN EDGE DIST. (inch)	SPECIMEN HOLE DIA. (inch)	PER PLY THICKNESS (inch)	PROPORTIONAL LIMIT LOAD (lbs)	YIELD LOAD (lbs)	ULTIMATE LOAD (lbs)	ACTUAL BEARING STRESS			NORMALIZED BEARING STRESS (2)			FAILURE MODE (3)
										PROPORTIONAL (ksi)	YIELD (ksi)	ULTIMATE (ksi)	PROPORTIONAL (ksi)	YIELD (ksi)	ULTIMATE (ksi)	
TPBR-01		1.501	0.136	0.749	0.249	0.00567	2700	2910	5800	79.73	85.93	171.27	78.44	84.54	168.50	(a)
TPBR-02		1.501	0.139	0.750	0.249	0.00579	2725	3210	5950	78.73	92.75	171.91	79.17	93.25	172.86	(a)
TPBR-03	-125°F/DRY	1.501	0.142	0.749	0.249	0.00592	2500	3230	6200	70.71	91.35	175.35	72.63	93.84	180.12	(a)
TPBR-04		1.501	0.139	0.749	0.249	0.00579	2850	3300	6240	82.34	95.35	180.29	82.80	95.87	181.28	(a)
TPBR-05		1.501	0.140	0.750	0.249	0.00583	2625	3500	6400	75.30	100.40	183.59	76.26	101.68	185.93	(a)
TPBR-06		1.501	0.138	0.748	0.249	0.00575	2660	3025	6050	77.41	88.03	176.07	77.28	87.88	175.76	(a)
	AVERAGE:	**1.501**	**0.139**	**0.749**	**0.249**	**0.00579**	**2677**	**3196**	**6107**	**77.37**	**92.30**	**176.41**	**77.76**	**92.84**	**177.41**	
	Minimum	1.501	0.136	0.748	0.249	0.00567	2500	2910	5800	70.71	85.93	171.27	72.63	84.54	168.50	
	Maximum	1.501	0.142	0.750	0.249	0.00592	2850	3500	6400	82.34	100.40	183.59	82.80	101.68	185.93	
	C.V., %:	0.00	1.44	0.10	0.00	1.44	4.33	6.50	3.55	5.20	5.62	2.71	4.33	6.50	3.55	
TPBR-07		1.501	0.138	0.750	0.249	0.00575	2000	2485	4890	58.20	72.32	142.31	58.10	72.19	142.06	(a)
TPBR-08		1.501	0.138	0.750	0.249	0.00575	2000	2375	5290	58.20	69.12	153.95	58.10	69.00	153.68	(a)
TPBR-09	RTD	1.501	0.139	0.750	0.249	0.00579	2170	2750	4985	62.70	79.45	144.03	63.04	79.89	144.82	(a)
TPBR-10		1.501	0.138	0.750	0.249	0.00575	2100	2800	4990	61.11	81.49	145.22	61.01	81.34	144.97	(a)
TPBR-11		1.500	0.137	0.750	0.249	0.00571	1850	2375	4500	54.23	69.62	131.91	53.75	69.00	130.73	(a)
TPBR-12		1.501	0.138	0.749	0.249	0.00575	1900	2150	4850	55.29	62.57	141.14	55.20	62.46	140.90	(a)
	AVERAGE:	**1.501**	**0.138**	**0.750**	**0.249**	**0.00575**	**2003**	**2489**	**4918**	**58.29**	**72.43**	**143.09**	**58.20**	**72.31**	**142.86**	
	Minimum	1.500	0.137	0.749	0.249	0.00571	1850	2150	4500	54.23	62.57	131.91	53.75	62.46	130.73	
	Maximum	1.501	0.139	0.750	0.249	0.00579	2170	2800	5290	62.70	81.49	153.95	63.04	81.34	153.68	
	C.V., %:	0.03	0.46	0.05	0.00	0.46	5.96	9.93	5.21	5.58	9.71	4.97	5.96	9.93	5.21	
TPBR-13		1.501	0.142	0.750	0.249	0.00592	1250	1860	3730	35.35	52.60	105.49	36.31	54.04	108.36	(a)
TPBR-14		1.501	0.142	0.750	0.249	0.00592	1115	1775	3635	31.53	50.20	102.81	32.39	51.57	105.60	(a)
TPBR-15	180°F/WET	1.501	0.139	0.749	0.249	0.00579	930	1650	3500	26.87	47.67	101.12	27.02	47.93	101.68	(a)
TPBR-16		1.501	0.141	0.750	0.249	0.00588	1190	1870	4005	33.89	53.26	114.07	34.57	54.33	116.35	(a)
TPBR-17		1.501	0.144	0.750	0.249	0.00600	1150	1840	4250	32.07	51.32	118.53	33.41	53.45	123.47	(a)
TPBR-18		1.501	0.143	0.750	0.249	0.00596	1015	1600	4005	28.51	44.93	112.48	29.49	46.48	116.35	(a)
	AVERAGE:	**1.501**	**0.142**	**0.750**	**0.249**	**0.00591**	**1108**	**1766**	**3854**	**31.37**	**50.00**	**109.08**	**32.20**	**51.30**	**111.97**	
	Minimum	1.501	0.139	0.749	0.249	0.00579	930	1600	3500	26.87	44.93	101.12	27.02	46.48	101.68	
	Maximum	1.501	0.144	0.750	0.249	0.00600	1250	1870	4250	35.35	53.26	118.53	36.31	54.33	123.47	
	C.V., %:	0.00	1.21	0.05	0.00	1.21	10.60	6.52	7.26	10.20	6.34	6.37	10.60	6.52	7.26	

NOTES:
1. Pin bearing tests were conducted and data were reduced in accordance with MIL-HDBK-17D, Volume 1, Section 7.2.4.
2. Normalized stresses are calculated using a nominal ply thickness of 0.00576 inch.
3. Failure modes:
   (a) Shearout Failure
4. Specimens had a laminate orientation of $[45/0/-45/90]_{3S}$
5. Wet specimens were moisture conditioned to an equilibrium moisture content of 1.193%.
6. Laminate ASDL 10379 had an average delta dB loss of 12.65.
7. Laminate physical properties:

LAMINATE ID	RESIN CONTENT (Wt. %)	FIBER VOLUME (Vol. %)	VOID VOLUME (Vol. %)	DENSITY ρ (lb/in^3)
ASDL 10379	30.81	59.63	2.31	0.055

Table 5. Pin Bearing Strength Test Results for CFS003/LTM25 Woven Cloth.

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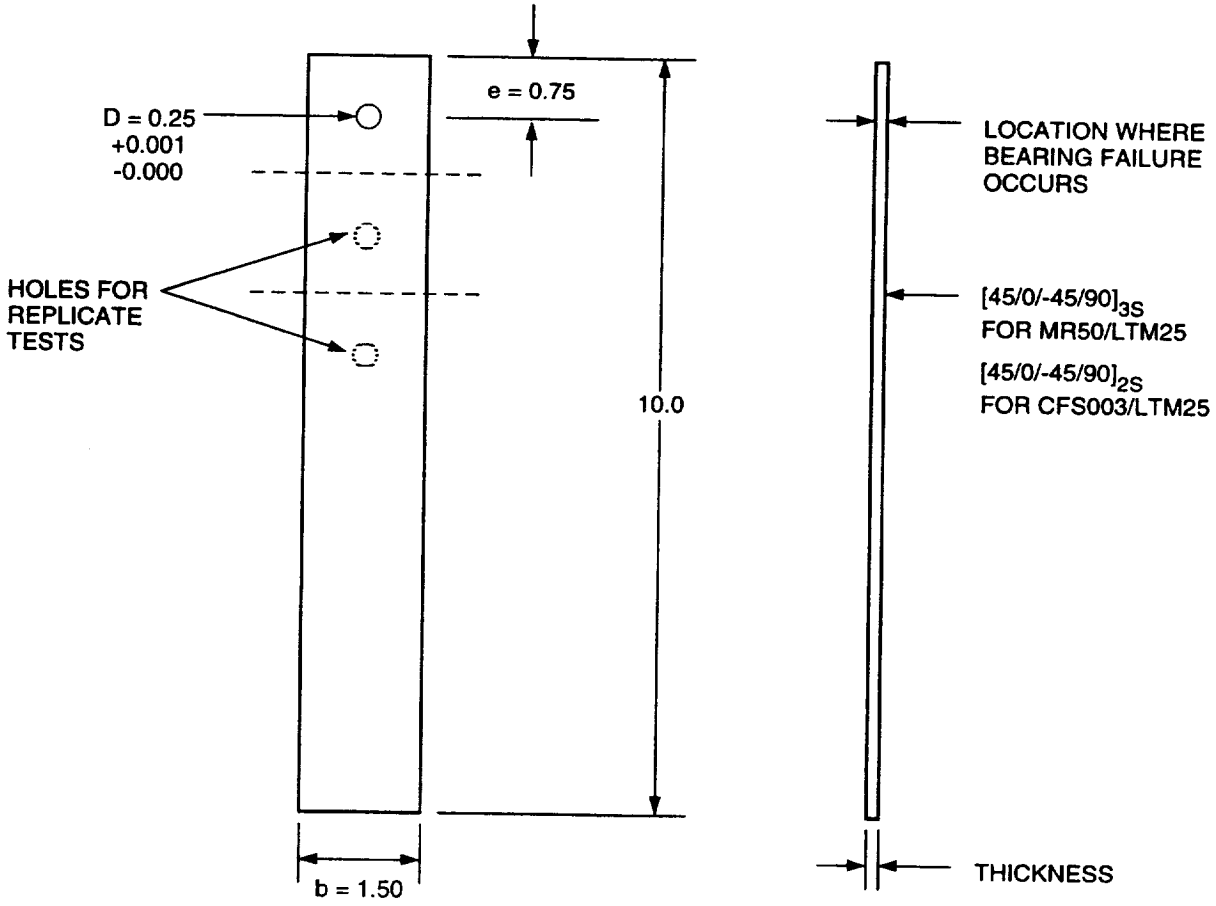
SPECIMEN ID	TEST ENVIRONMENT	SPECIMEN WIDTH (inch)	SPECIMEN THICKNESS (inch)	SPECIMEN EDGE DIST. (inch)	SPECIMEN HOLE DIA. (inch)	PER PLY THICKNESS (inch)	PROMOTIONAL LIMIT LOAD (lbs)	YIELD LOAD (lbs)	ULTIMATE LOAD (lbs)	ACTUAL BEARING STRESS PROPORTIONAL (ksi)	ACTUAL BEARING STRESS YIELD (ksi)	ACTUAL BEARING STRESS ULTIMATE (ksi)	NORMALIZED BEARING STRESS (2) PROPORTIONAL (ksi)	NORMALIZED BEARING STRESS (2) YIELD (ksi)	NORMALIZED BEARING STRESS (2) ULTIMATE (ksi)	FAILURE MODE (3)
WPBR-01		1.501	0.154	0.750	0.249	0.00963	3120	3320	5060	81.36	86.58	131.96	86.63	92.18	140.50	(b)
WPBR-02		1.501	0.153	0.750	0.249	0.00956	3260	3710	4915	85.57	97.38	129.01	90.52	103.01	136.47	(b)
WPBR-03	-125°F/DRY	1.501	0.152	0.750	0.249	0.00950	3305	4020	5050	87.32	106.21	133.43	91.77	111.62	140.22	(b)
WPBR-04		1.501	0.155	0.750	0.249	0.00969	3490	3820	4985	90.43	98.98	129.16	96.90	106.07	138.41	(b)
WPBR-05		1.500	0.153	0.750	0.249	0.00956	2830	3370	5020	74.28	88.46	131.77	78.58	93.57	139.38	(b)
WPBR-06		1.500	0.153	0.750	0.249	0.00958	2925	3175	4925	76.78	83.34	129.28	81.22	88.16	136.75	(b)
	AVERAGE:	**1.501**	**0.153**	**0.750**	**0.249**	**0.00958**	**3155**	**3569**	**4993**	**82.62**	**93.49**	**130.77**	**87.60**	**99.10**	**138.62**	
	Minimum	1.500	0.152	0.750	0.249	0.00950	2830	3175	4915	74.28	83.34	129.01	78.58	88.16	136.47	
	Maximum	1.501	0.155	0.750	0.249	0.00969	3490	4020	5060	90.43	106.21	133.43	96.90	111.62	140.50	
	C.V., %:	0.03	0.67	0.00	0.00	0.67	7.83	9.23	1.24	7.60	9.36	1.43	7.83	9.23	1.24	
WPBR-07		1.500	0.155	0.749	0.249	0.00969	2280	2200	3340	59.08	57.00	86.54	63.31	61.09	92.74	(d)
WPBR-08		1.501	0.156	0.750	0.249	0.00975	2535	2590	3670	65.26	66.68	94.48	70.39	71.91	101.90	(c)
WPBR-09	RTD	1.500	0.155	0.750	0.249	0.00969	2650	2300	3425	68.66	59.59	88.74	73.58	63.86	95.10	(c)
WPBR-10		1.500	0.155	0.750	0.249	0.00969	2600	-	-	67.37	-	-	72.19	-	-	(e)
WPBR-11		1.500	0.154	0.748	0.249	0.00963	2730	2320	3400	71.19	60.50	88.67	75.80	64.42	94.40	(c)
WPBR-12		1.500	0.154	0.750	0.249	0.00963	2620	2375	3370	68.33	61.94	87.88	72.75	65.94	93.57	(c)
	AVERAGE:	**1.500**	**0.155**	**0.750**	**0.249**	**0.00968**	**2569**	**2357**	**3441**	**66.65**	**61.14**	**89.26**	**71.34**	**65.44**	**95.54**	
	Minimum	1.500	0.154	0.748	0.249	0.00963	2280	2200	3340	59.08	57.00	86.54	63.31	61.09	92.74	
	Maximum	1.501	0.156	0.750	0.249	0.00975	2730	2590	3670	71.19	66.68	94.48	75.80	71.91	101.90	
	C.V., %:	0.03	0.49	0.11	0.00	0.49	6.05	6.14	3.83	6.27	5.85	3.41	6.05	6.14	3.83	
WPBR-13		1.500	0.155	0.750	0.249	0.00969	1750	2025	3575	45.34	52.47	92.63	48.59	56.23	99.26	(a)
WPBR-14		1.500	0.158	0.750	0.249	0.00988	1660	2325	3625	42.19	59.10	92.14	46.09	64.56	100.65	(a)
WPBR-15	180°F/WET	1.499	0.160	0.749	0.249	0.01000	1500	2210	3675	37.65	55.47	92.24	41.65	61.36	102.04	(a)
WPBR-16		1.500	0.156	0.750	0.249	0.00975	1440	1975	3525	37.07	50.84	90.75	39.98	54.84	97.87	(a)
WPBR-17		1.498	0.156	0.750	0.249	0.00975	1580	2050	3675	40.68	52.78	94.61	43.87	56.92	102.04	(a)
WPBR-18		1.499	0.156	0.750	0.249	0.00975	1620	2025	3860	41.71	52.13	99.37	44.98	56.23	107.18	(d)
	AVERAGE:	**1.499**	**0.157**	**0.750**	**0.249**	**0.00980**	**1592**	**2102**	**3656**	**40.77**	**53.80**	**93.62**	**44.19**	**58.35**	**101.51**	
	Minimum	1.498	0.155	0.749	0.249	0.00969	1440	1975	3525	37.07	50.84	90.75	39.98	54.84	97.87	
	Maximum	1.500	0.160	0.750	0.249	0.01000	1750	2325	3860	45.34	59.10	99.37	48.59	64.56	107.18	
	C.V., %:	0.05	1.17	0.05	0.00	1.17	7.00	6.46	3.17	7.54	5.59	3.29	7.00	6.46	3.17	

NOTES: 1. Pin bearing tests were conducted and data were reduced in accordance with MIL-HDBK-17D, Volume 1, Section 7.2.4.
Proportional limit loads are higher than yields load for RTD tests per data reduction procedure delineated by MIL-HDBK-17D
2. Normalized stresses are calculated using a nominal ply thickness of 0.00904 inch.
3. Failure modes:
(a) Shearout Failure
(b) Net Section Tension Failure
(c) Bearing Failure
(d) Cleavage - Tension Failure
(e) Specimen WPBR-10 test was stopped prematurely by equipment failure.
4. Specimens had a laminate orientation of $[45/0/-45/90]_{2S}$
5. Wet specimens were moisture conditioned to an equilibrium moisture content of 1.199%.
6. Laminate ASDL 10380 had an average delta dB loss of 9.10.
7. Laminate physical properties:

LAMINATE ID	RESIN CONTENT (Wt. %)	FIBER VOLUME (Vol. %)	VOID VOLUME (Vol. %)	DENSITTY ρ (lb/in^3)
ASDL 10380	43.63	46.79	1.51	0.052



ALL DIMENSIONS IN INCHES

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FIGURE 1. TEST SPECIMEN GEOMETRY.

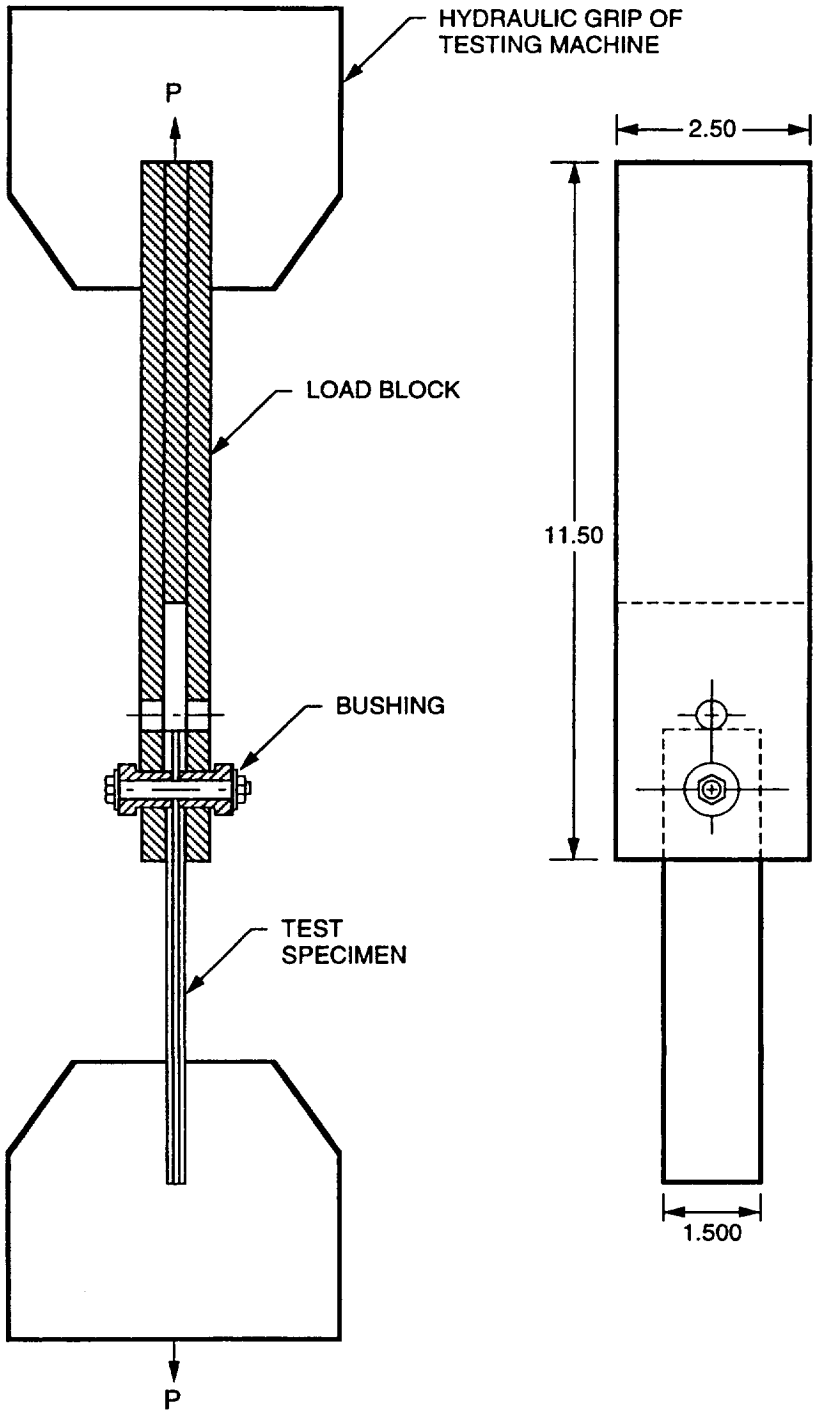

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FIGURE 2. TEST ARRANGEMENT FOR MATERIAL BEARING STRENGTH MEASUREMENT.

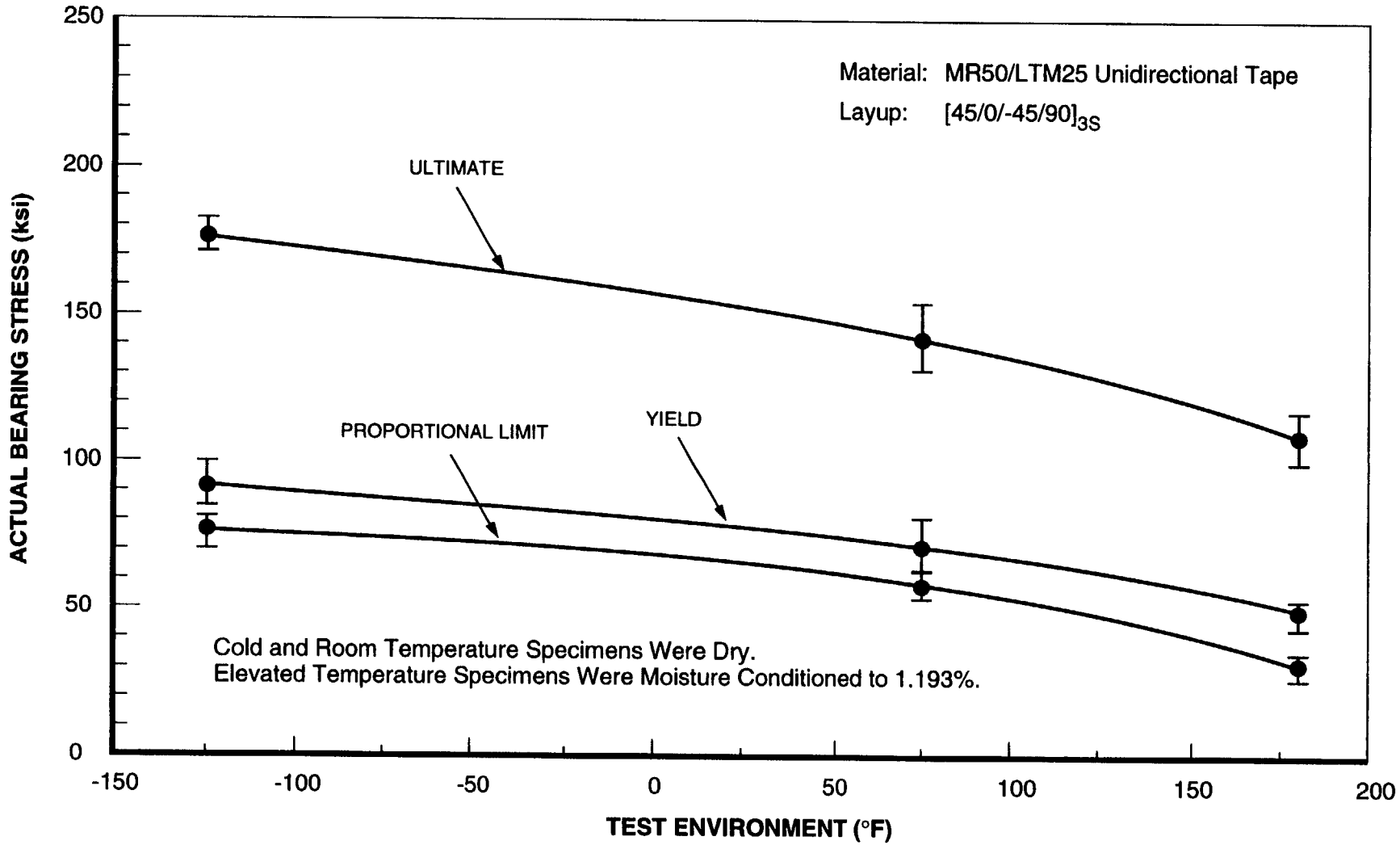

FIGURE 3. PIN BEARING STRENGTH TEST RESULTS FOR MR50/LTM25 UNIDIRECTIONAL TAPE.

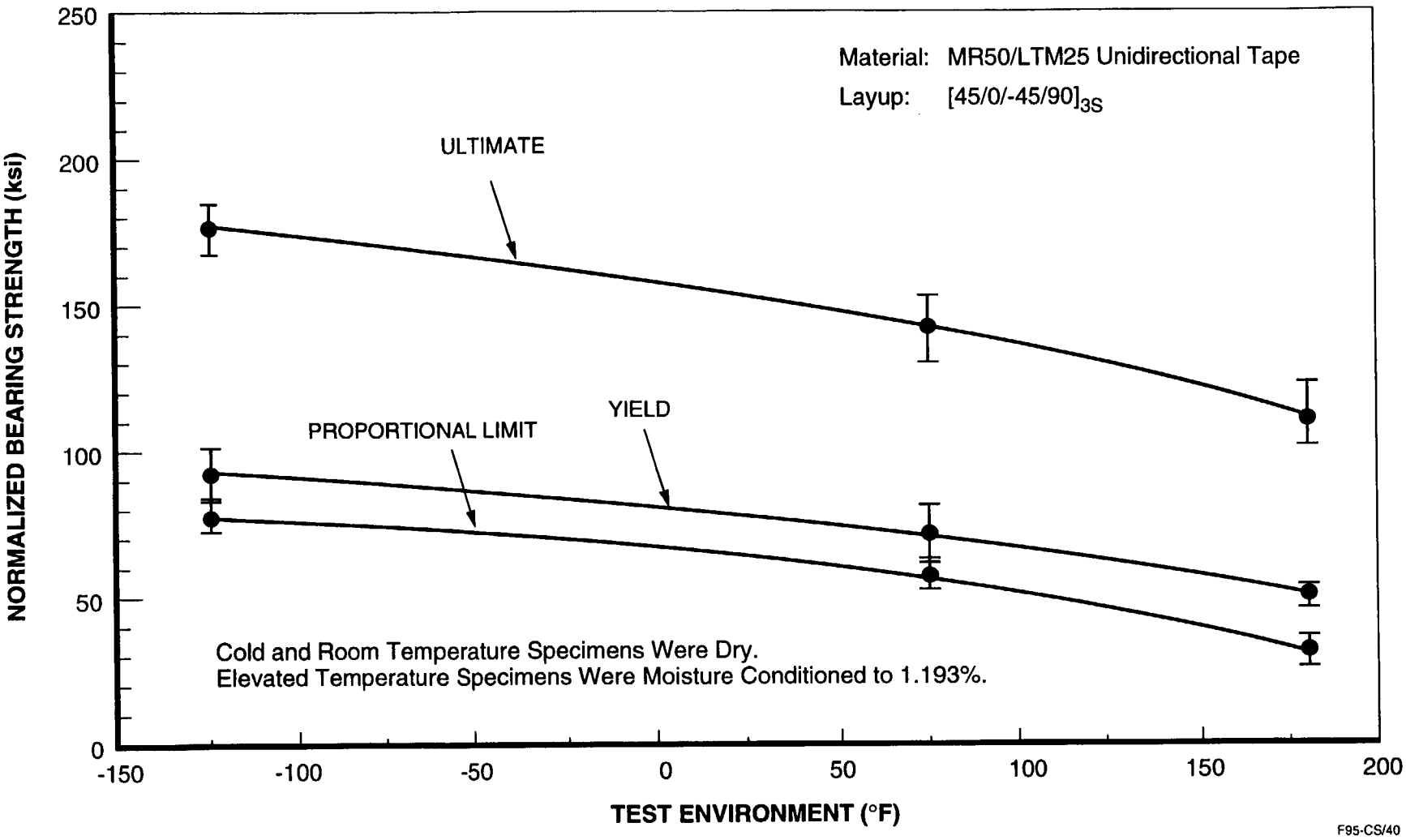

FIGURE 4. PIN BEARING STRENGTH TEST RESULTS FOR MR50/LTM25 UNIDIRECTIONAL TAPE.

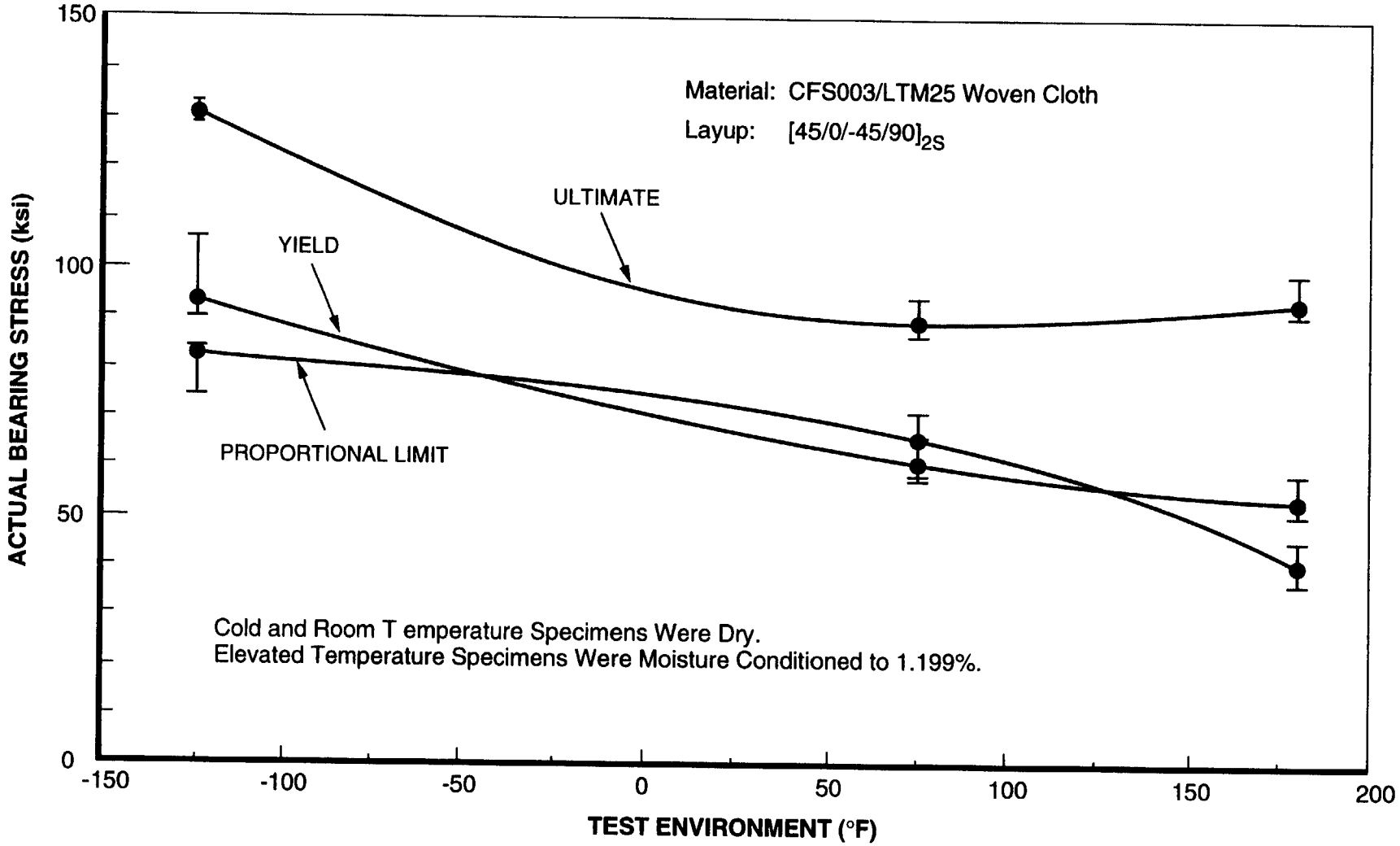

FIGURE 5. PIN BEARING STRENGTH TEST RESULTS FOR CFS003/LTM25 WOVEN CLOTH.

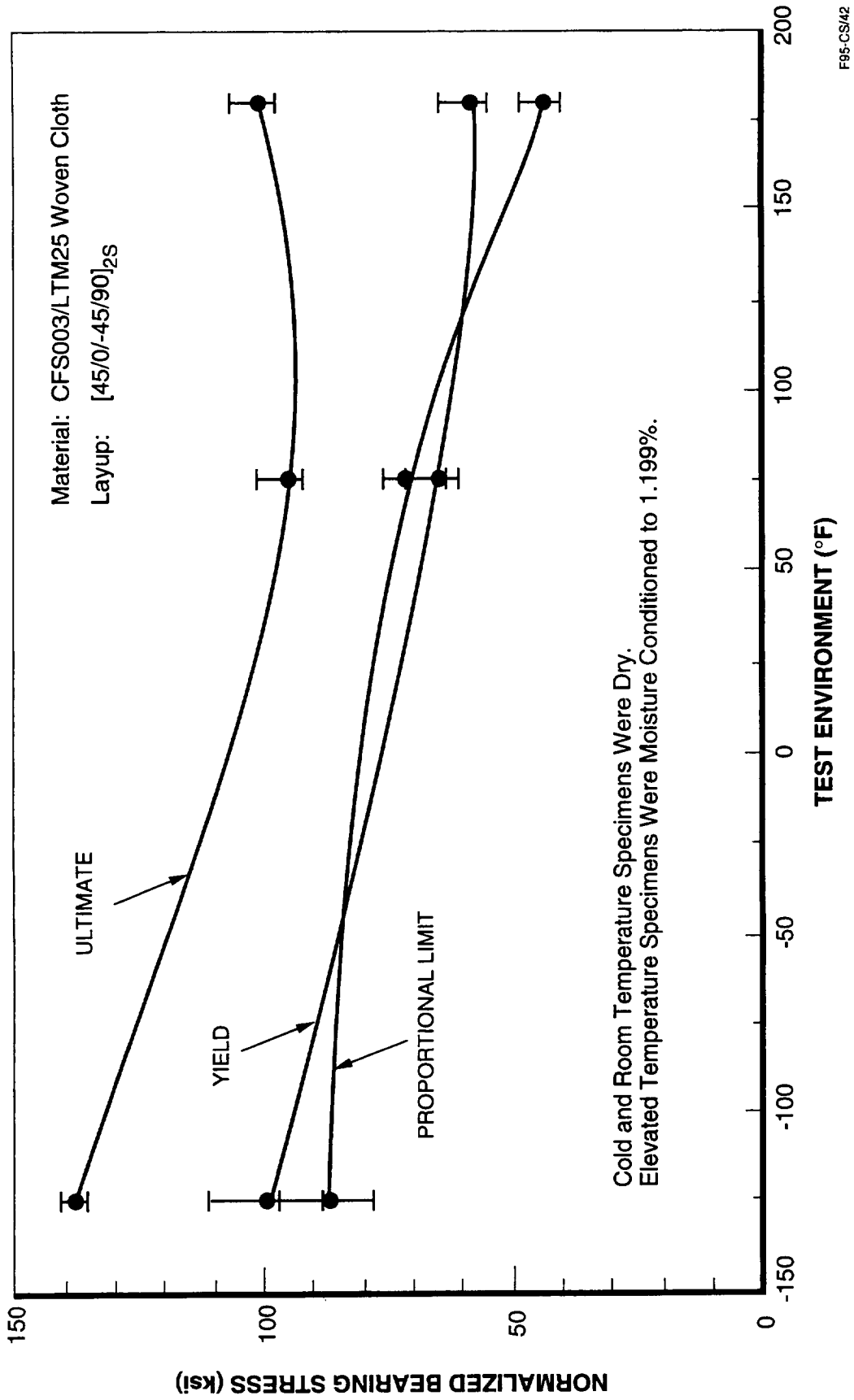

FIGURE 6. PIN BEARING STRENGTH TEST RESULTS FOR CFS003/LTM25 WOVEN CLOTH.

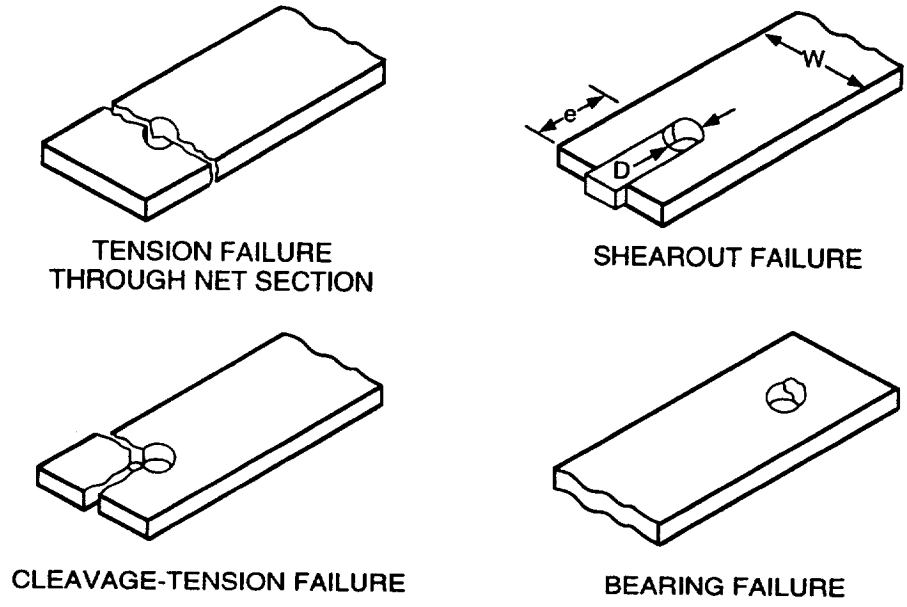

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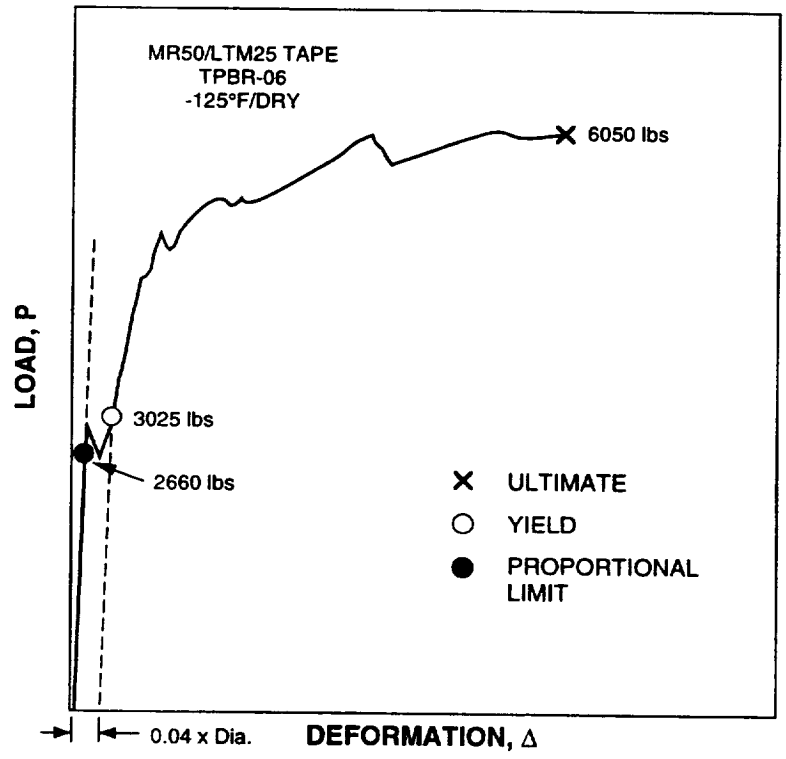
FIGURE 7. TYPICAL FAILURE MODES FOR DOUBLE SHEAR PIN BEARING.



F95-CS/49

FIGURE 8. PIN-BEARING LOAD-DISPLACEMENT RESPONSE FOR SPECIMEN TPBR-06.

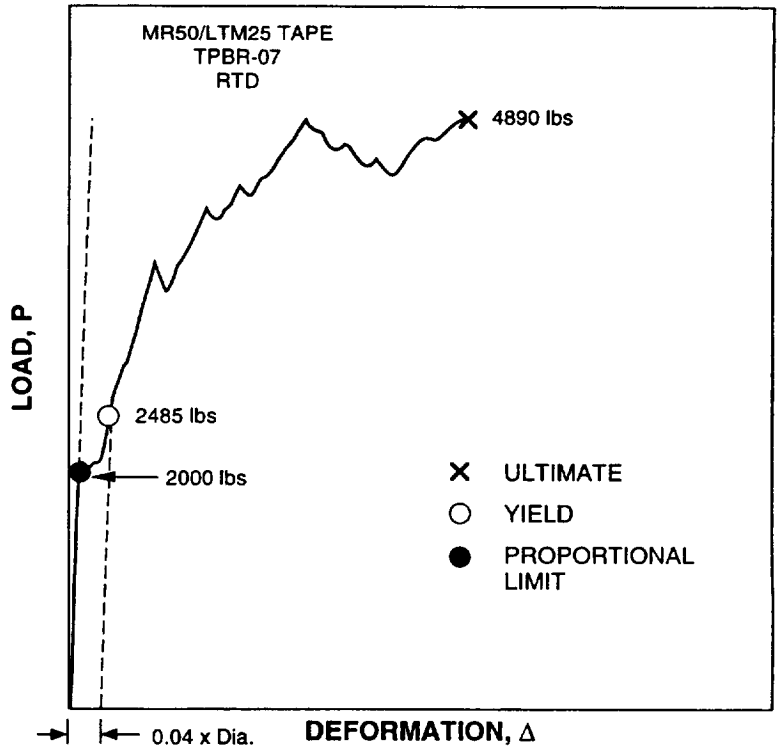


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FIGURE 9. PIN-BEARING LOAD-DISPLACEMENT RESPONSE FOR SPECIMEN TPBR-07.

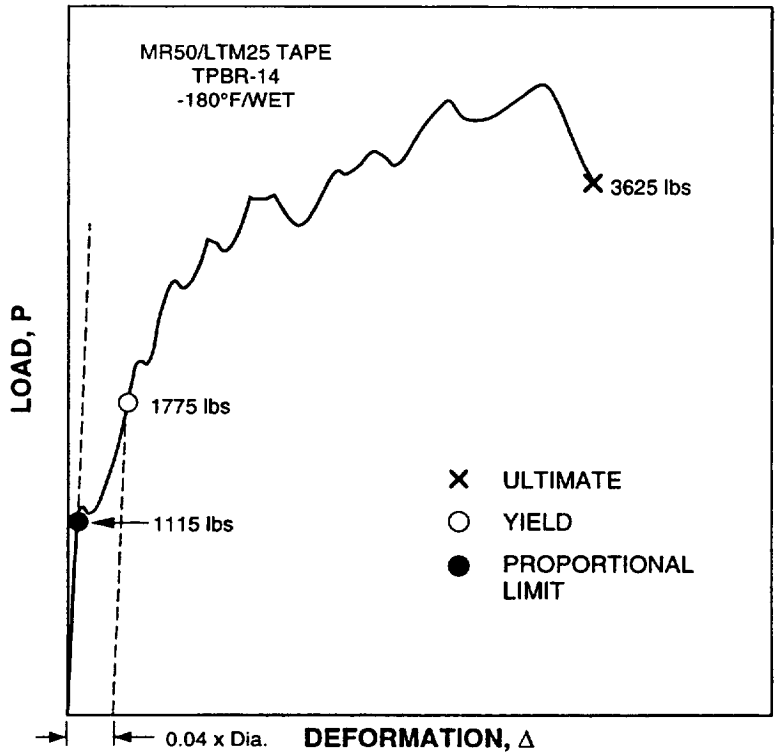

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FIGURE 10. PIN-BEARING LOAD-DISPLACEMENT RESPONSE FOR SPECIMEN TPBR-14.

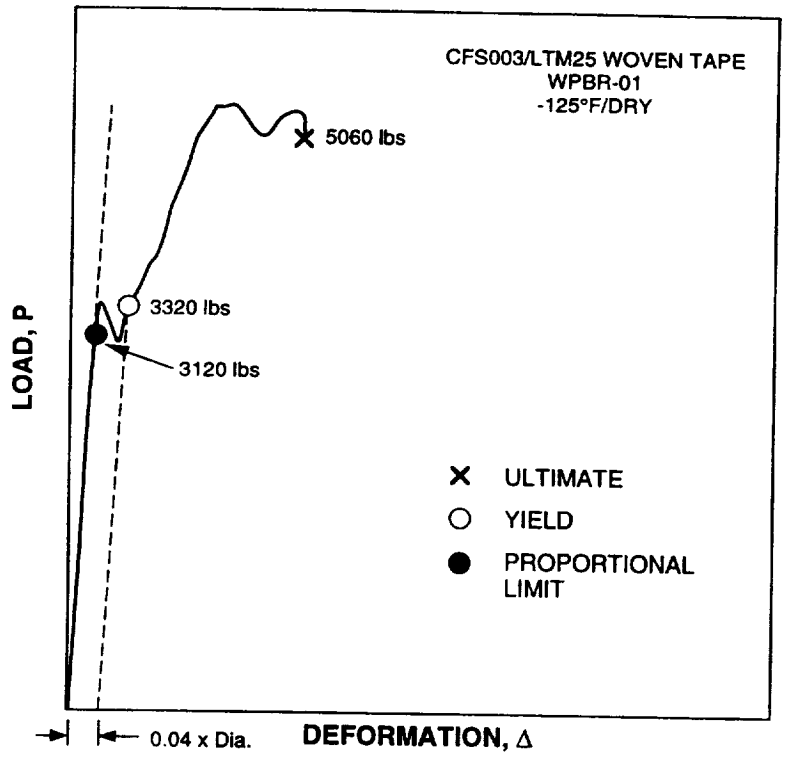

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FIGURE 11. PIN-BEARING LOAD-DISPLACEMENT RESPONSE FOR SPECIMEN WPBR-01.

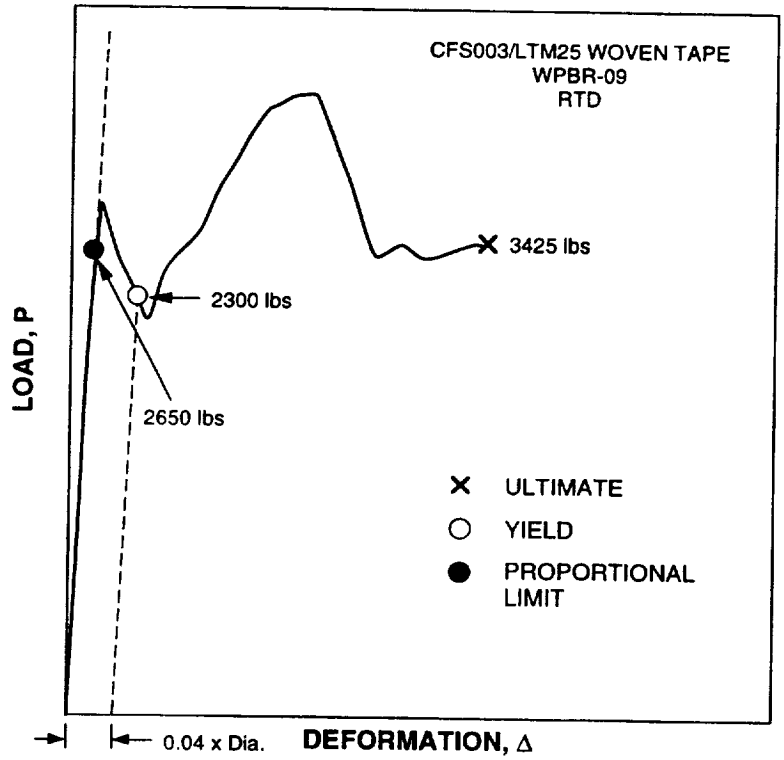

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FIGURE 12. PIN-BEARING LOAD-DISPLACEMENT RESPONSE FOR SPECIMEN WPBR-08.

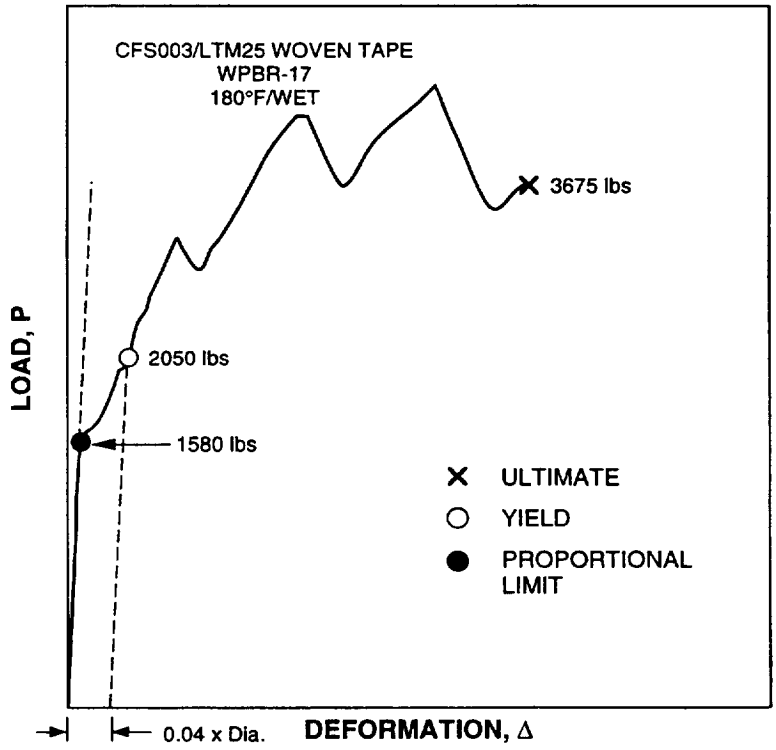

FIGURE 13. PIN-BEARING LOAD-DISPLACEMENT RESPONSE FOR SPECIMEN WPBR-17.

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13. ABSTRACT (*Maximum 200 words*)

This report summarizes the work performed on NASA contract NAS1-19347, Task 18. Task 18 is an add on to Task 14 of the same contract. Under Task 18, Northrop Grumman Corporation was contracted by NASA Langley to conduct pin bearing testing and fabricate two panels from composite materials that cure at low temperatures. These materials are being incorporated into Unmanned Aerial Vehicles (UAVs) to reduce manufacturing costs since they allow the use of low-cost tooling and facilities. Two composite prepreg product forms were evaluated; MR50/LTM25 unidirectional tape, batch 288lvd and CFS003/LTM25 woven cloth, batch 2216. Northrop Grumman fabricated, machined, and tested specimens to determine the bearing strength in accordance with MIL-HDBK-17D, Volume 1, Section 7.2.4. Quasi-isotropic laminates from the two product forms were fabricated for these tests. In addition, 2 quasi-isotropic panels of dimensions 12"x28" were fabricated (one each from the two product forms), inspected, and shipped to NASA Langley for further evaluation. The method of manufacture and inspection was similar to that used for the Contract NAS1-19347, Task 14 and they are documented in detail in the final report titled "Property Evaluation of LTM25 Composite Materials."

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